Sea Ice Deformation in a Coupled Sea Ice-Ocean Model and from Satellite Remote Sensing: Comparison and Model Adaptation

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Outline

Comparison of observed RGPS SAR sea ice deformation fields to results from a traditional viscous-plastic sea ice model

- Motivation
- Model and Data
- Comparison
  - Dependence on model resolution
  - Exponential scaling of sea ice deformation
  - Dependence on model sea ice strength formulation
- Conclusions

Motivation (1)

Sea ice deformation in the Arctic climate system:

- Divergence creates open water → new ice growth in winter
- Convergence creates pressure ridges → thicker ice
- Controls heat and moisture fluxes to the atmosphere and brine rejection to the ocean
- Alters the air and water drag coefficients

➔ Correct modeling of sea ice kinematics important for sea ice mass balance and ocean – air energy fluxes

Motivation (2)

Sea ice model evaluation with ice deformation fields:

- Even simple models with wrong sea ice physics can simulate the mean sea ice velocity field correctly [e.g. Rampal et al., 2009].
- Comparisons with first order mean velocity fields therefore **not sufficient**. Second order **sea ice deformation should be used**.

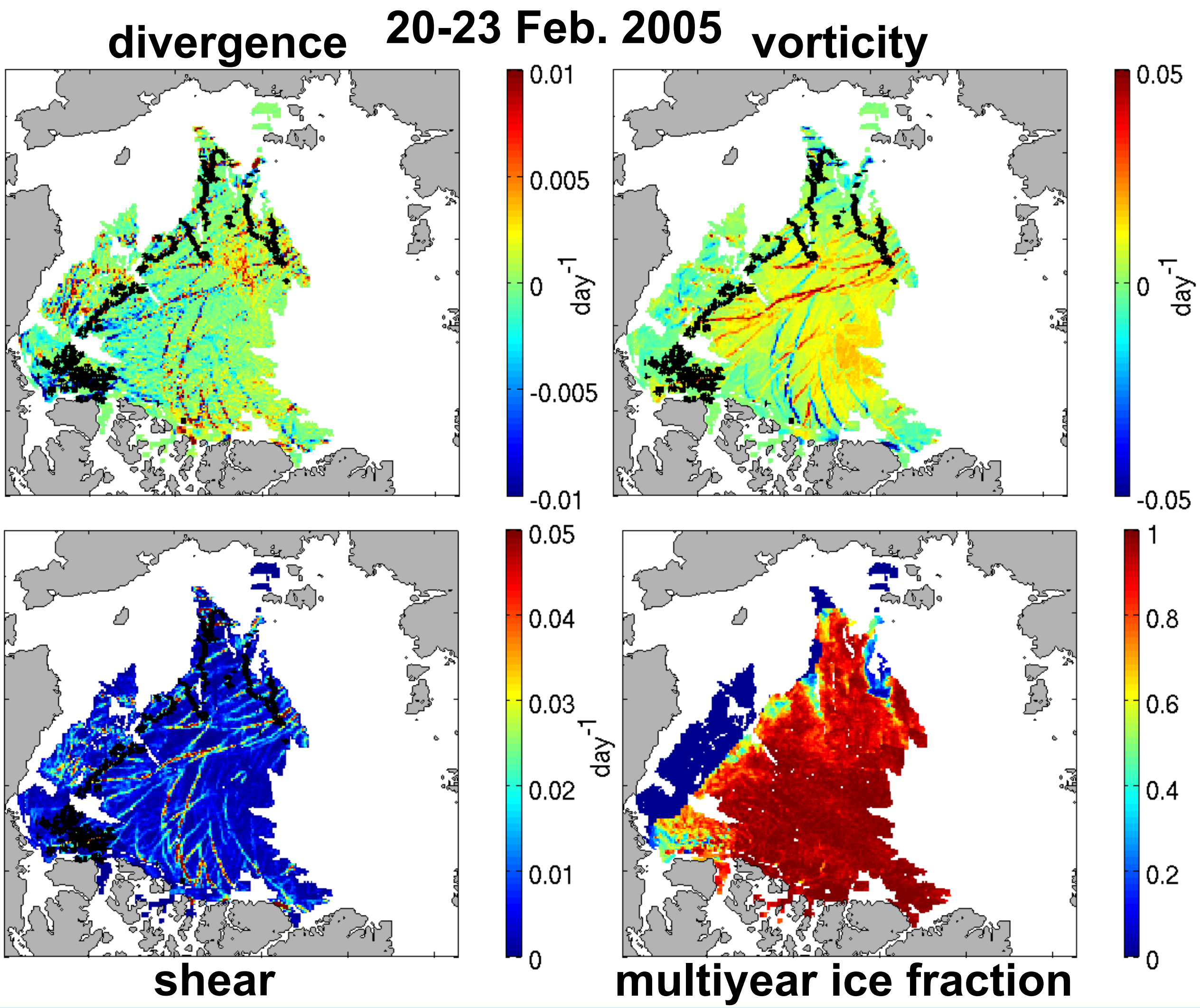
Tuning a traditional Hibler-type viscous-plastic sea ice model with elliptical yield curve

- Sea ice deformation field is not represented correctly in all details
- But it is widely used in climate research.

➔ Tune model to best represent observed sea ice kinematics

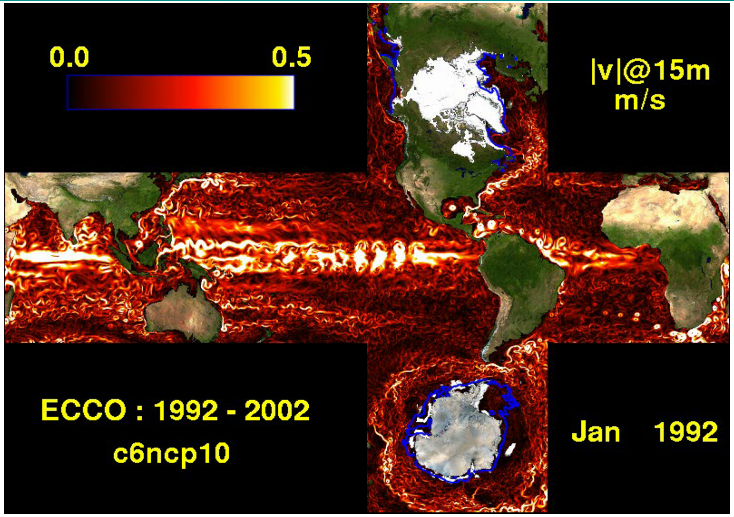
RGPS Satellite Data

- RADARSAT Synthetic Aperture Radar (SAR) data
- Same region covered approx. every 3 days
- Spatial cross-correlation of patterns → ice movement

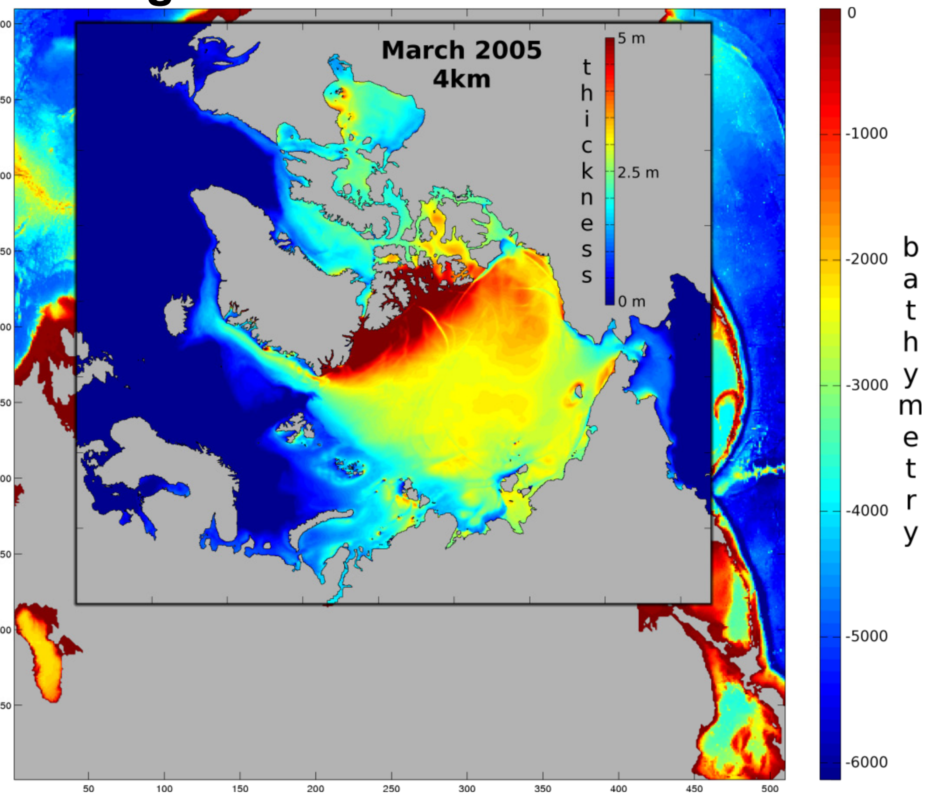


- Initial grid spacing 10 km
- Calculation of deformation (divergence, vorticity, shear) from Lagrangian cells
- 3 daily gridded (12.5 km)
- Accuracy of ice velocities in the order of 100 m (SAR pixel size)
- Discrimination between first- and multiyear ice

ECCO2 Coupled Sea Ice-Ocean Model



Regional Arctic solution:



ECCO2: High-resolution global ocean and sea ice model constrained by least squares fit to available satellite and in-situ data (Green's function approach).

Ocean model

- 50 vertical levels, volume-conserving, C-grid
- Surface boundary conditions: JRA-25
- Initial conditions: WOA05

Sea ice model

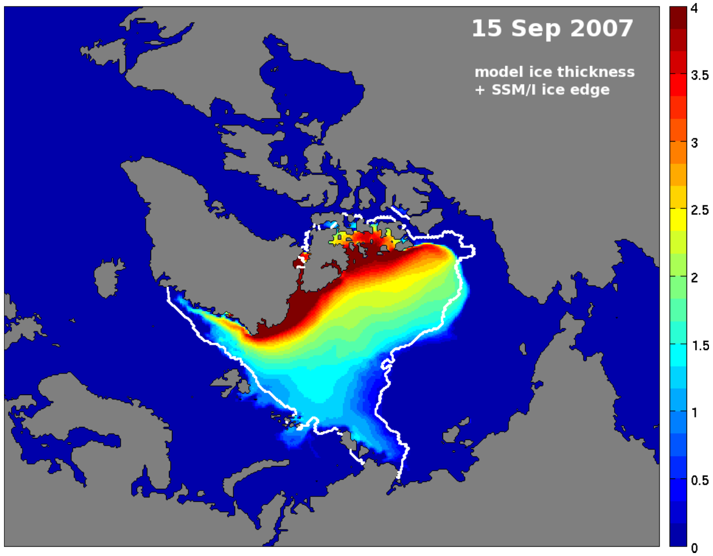
- 2-category zero-layer thermodynamics [Hibler, 1980]
- Viscous plastic dynamics [Hibler, 1979]
- Initial conditions: Polar Science Center
- Snow simulation: [Zhang et al., 1998]

Regional Arctic solution

- 4.5, 9 and 18 km horizontal grid spacing.
- Boundary conditions from global solution.
- Bathymetry: IBCAO
- Time: 1992 – 2009 (18 years)

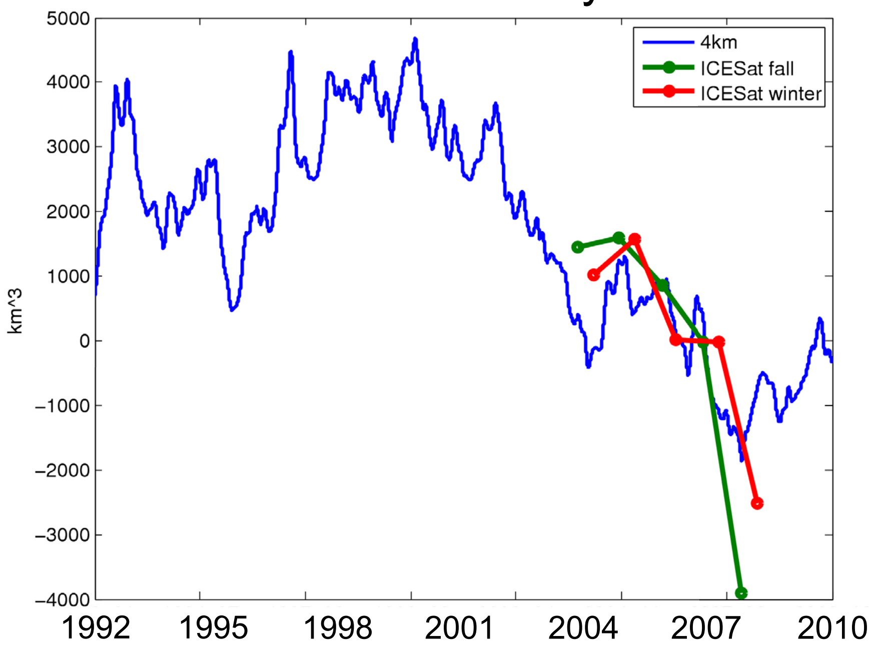
Model Performance

Sea ice minimum 2007

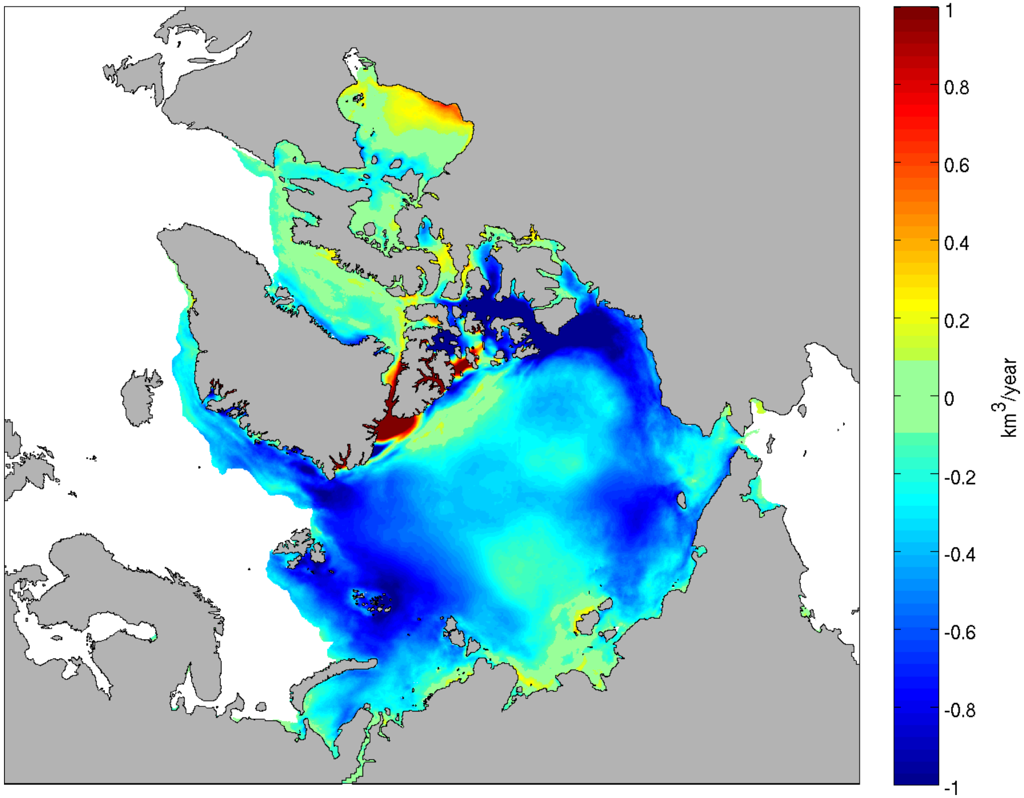


- Model is doing well in terms of sea ice extent but is tuned to do so ☺
- Changes in ice volume are comparable to observed ones using ICESat data (Kwok et al., 2009)

Sea ice volume anomaly 1992-2009

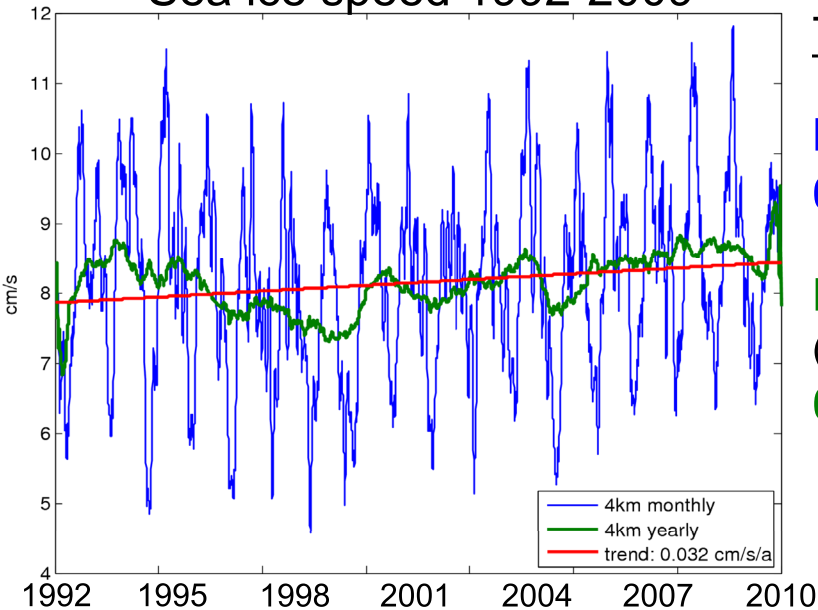


Trend in sea ice volume (1992-2009)



Sea Ice Speed

Sea ice speed 1992-2009

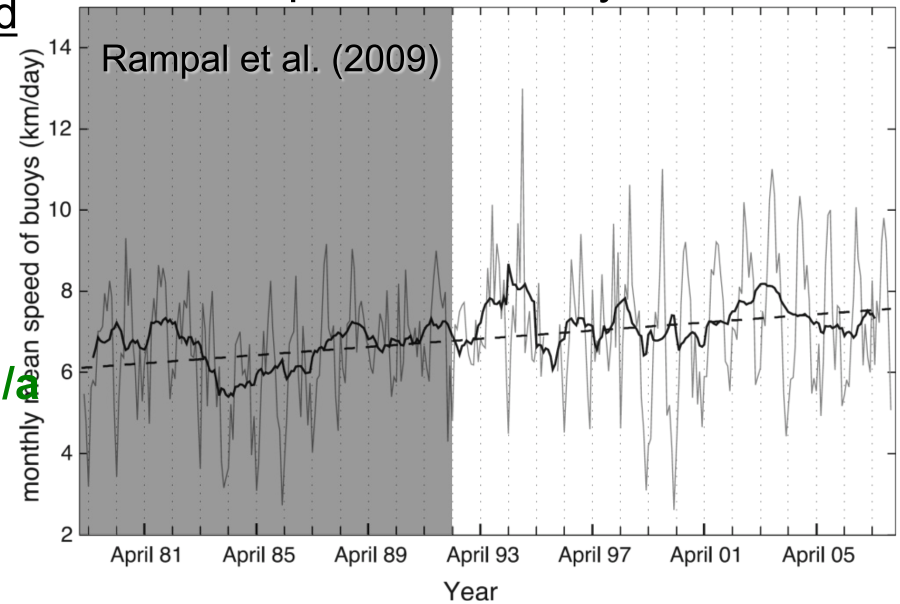


Trend sea ice speed

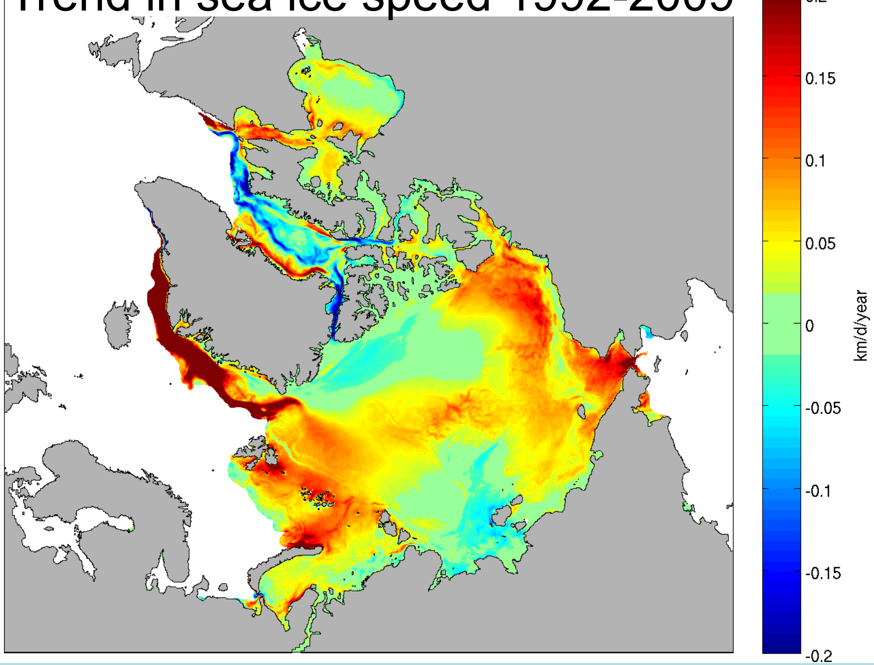
Model 1992-2008:
0.028 km/d/a

Buoy 1979-2007
(Rampal et al., 2009):
0.056 ± 0.011 km/d/a

Sea ice speed from buoys 1979-2007

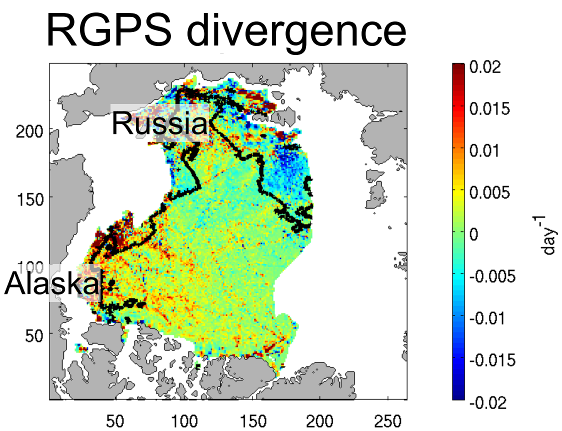


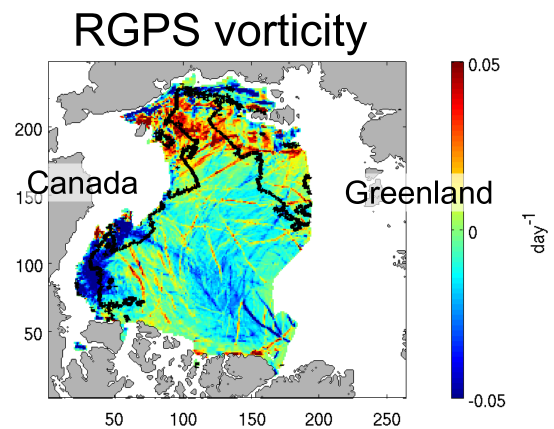
Trend in sea ice speed 1992-2009

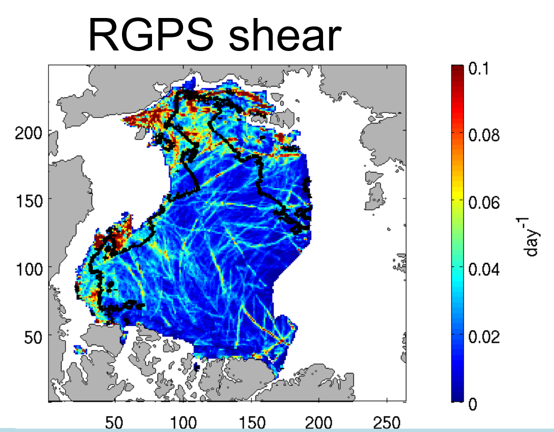


- Buoy observations and model show increase in mean sea ice speed
- Increase in speed is higher for buoys but different regions and periods are considered
- Strongest increase in west Beaufort Sea and Transpolar Drift

RGPS and Model Sea Ice Deformation



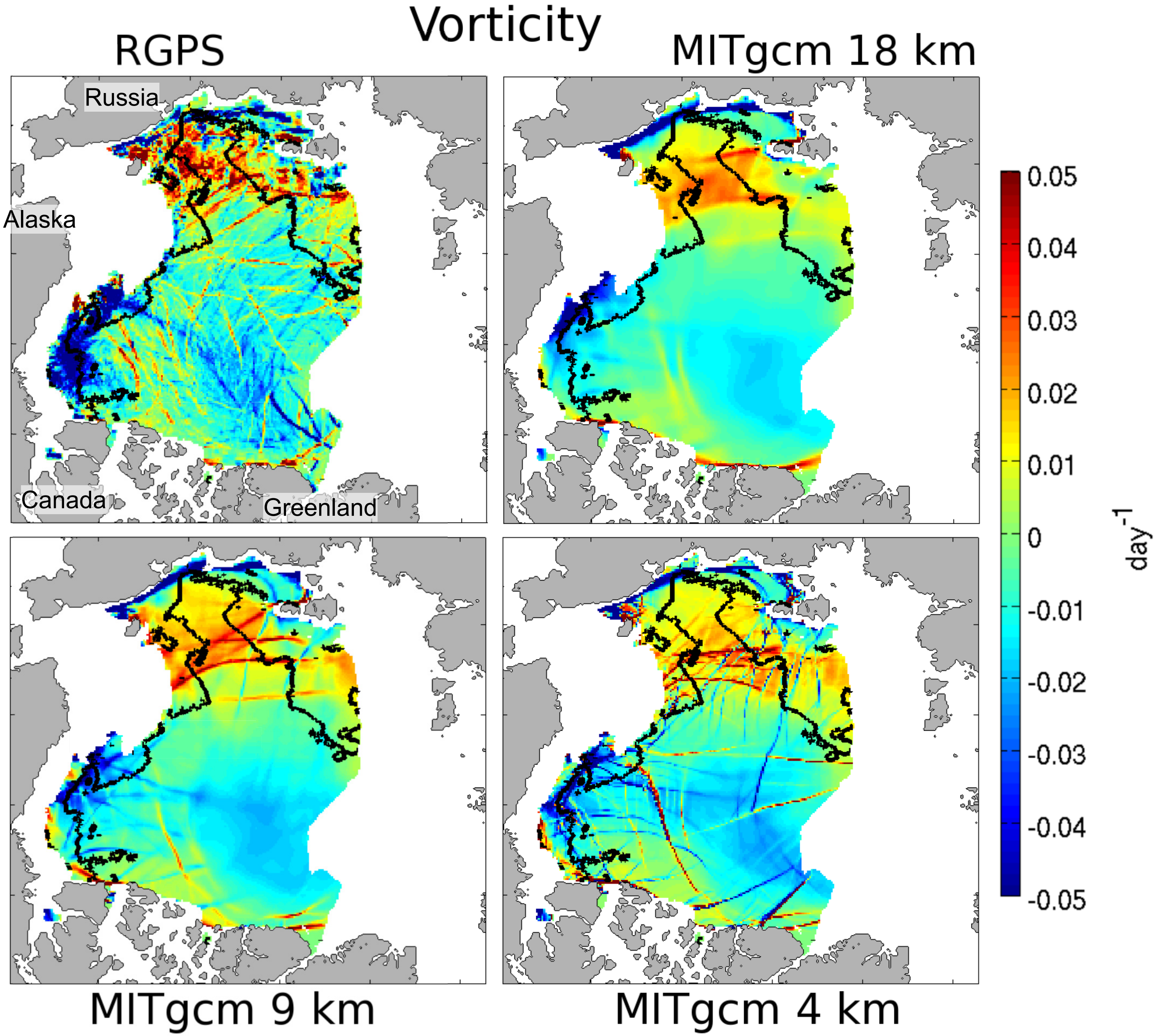




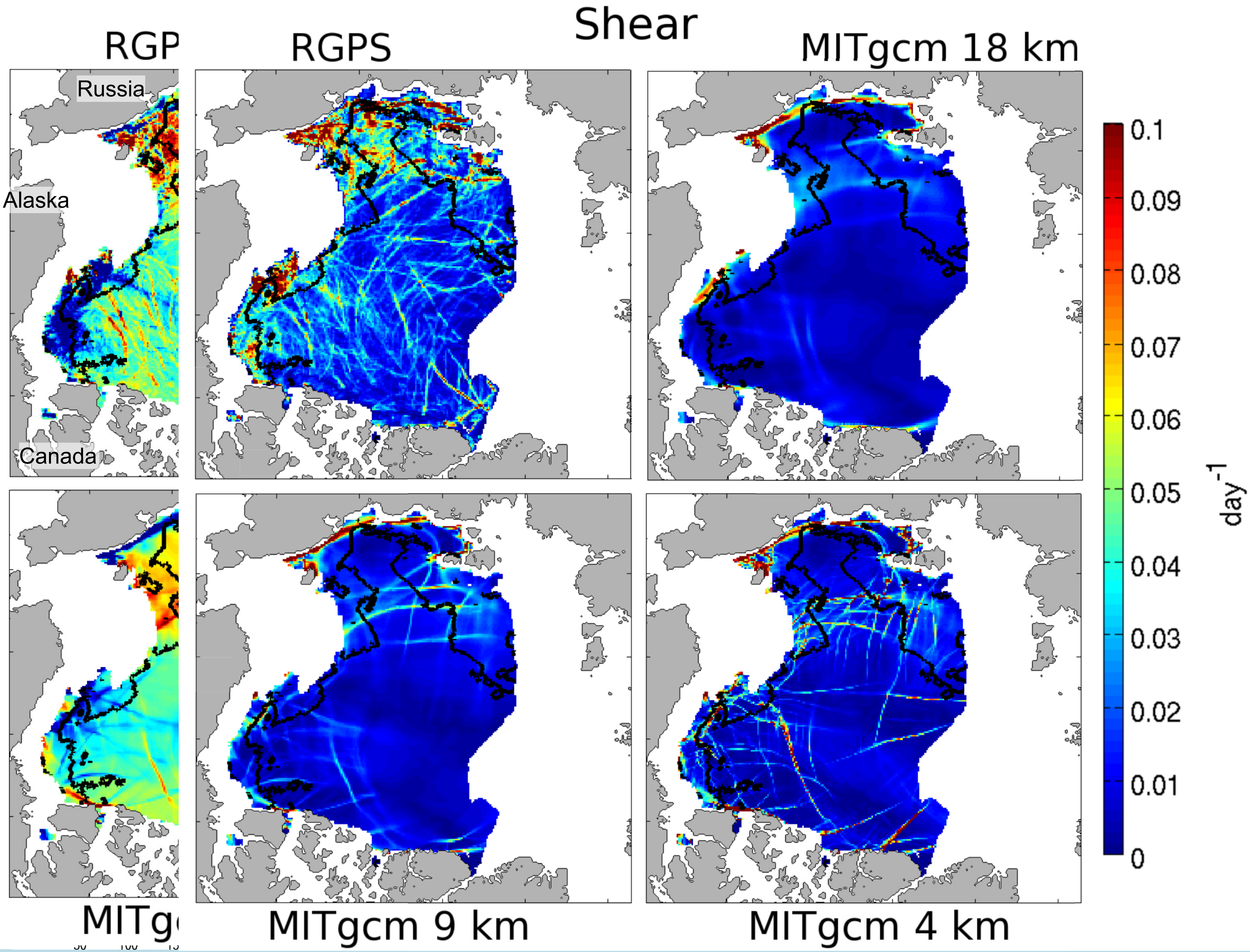
- Sea ice deformation parameters: divergence, vorticity and shear
- Example: November 1997

  black line: perennial ice

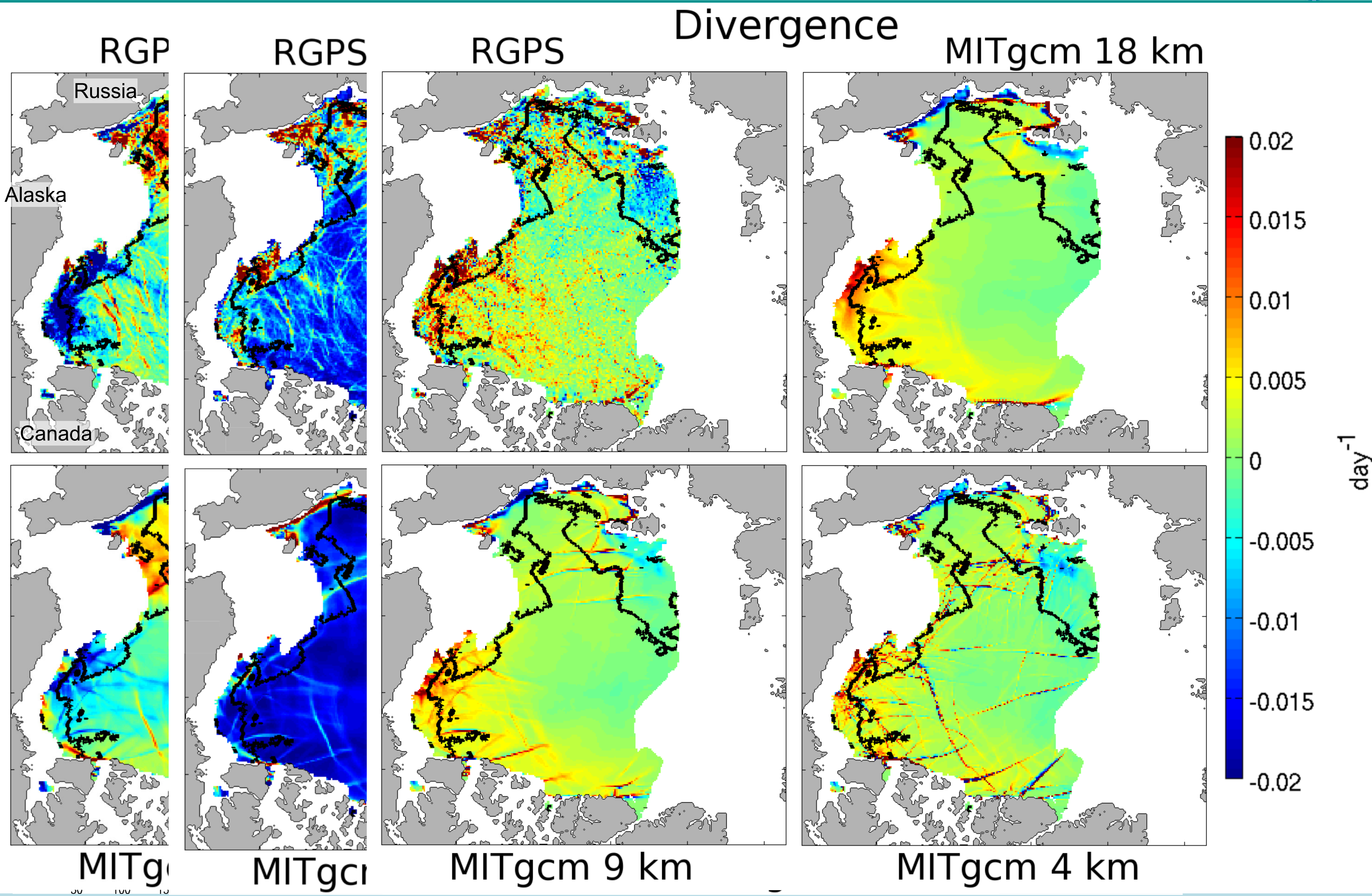
RGPS and Model Sea Ice Deformation



RGPS and Model Sea Ice Deformation

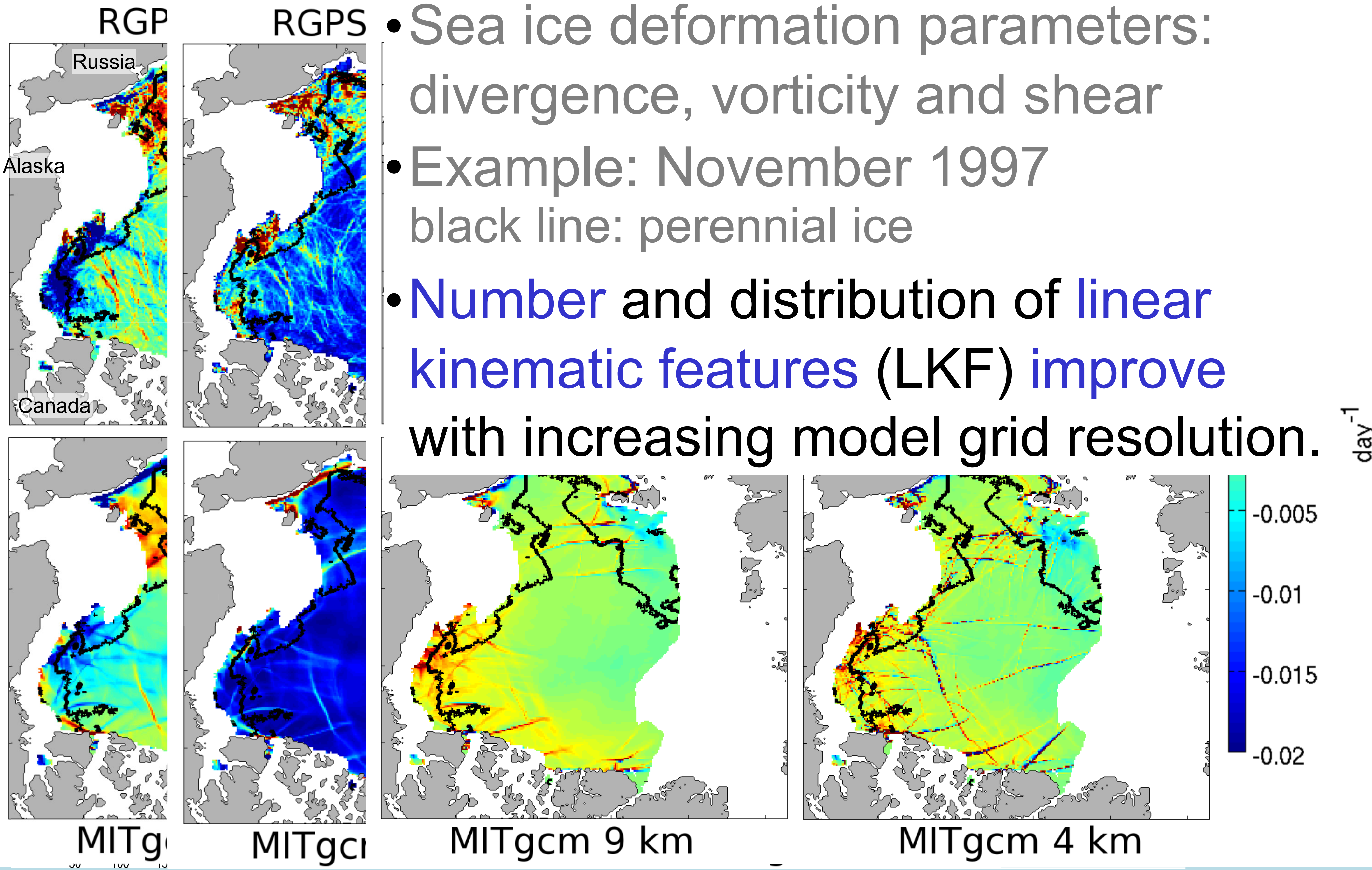


RGPS and Model Sea Ice Deformation



RGPS and Model Sea Ice Deformation

- Sea ice deformation parameters: divergence, vorticity and shear
- Example: November 1997
  black line: perennial ice
- Number and distribution of linear kinematic features (LKF) improve with increasing model grid resolution.



Spatial Scaling of Deformation Rate

- Deformation rate D:

$$D = \sqrt{\mathrm{div}^2 + \mathrm{shear}^2}$$

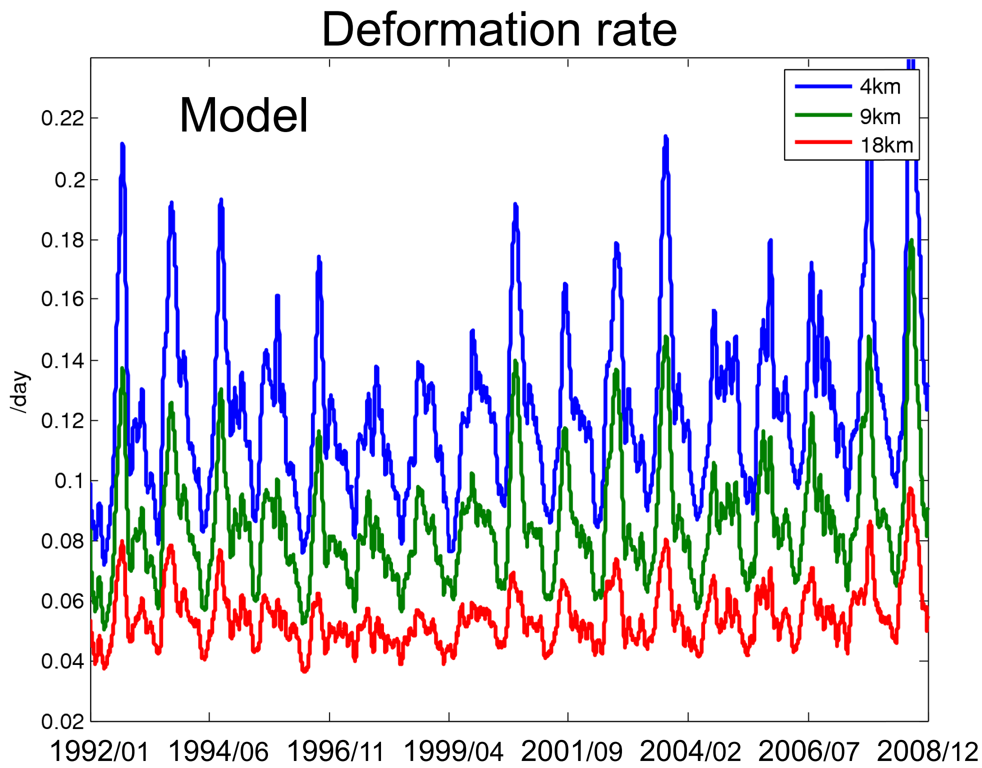
- The absolute amount of deformation D depends exponentially on the spatial scale L over which it is measured.
- From RGPS observations (Stern & Lindsay, 2009):

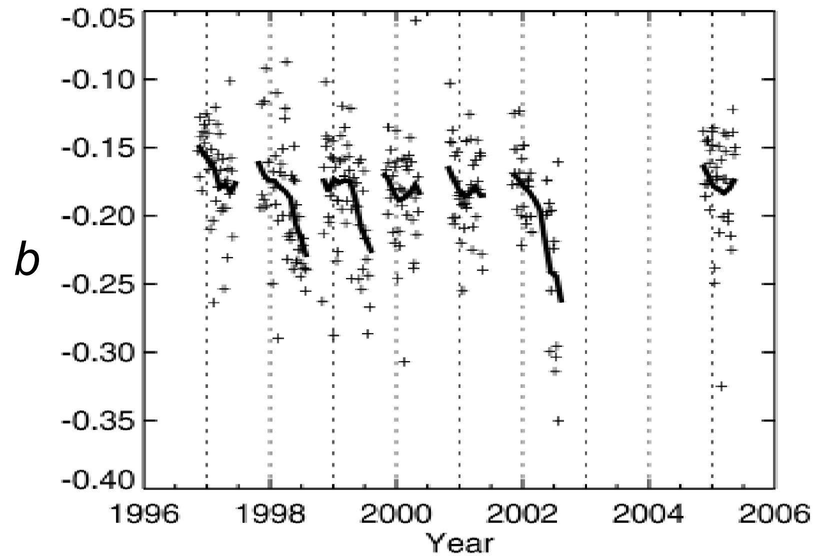
$$D \approx d\,L^b$$

$$b = -0.2 \quad \text{(winter)}$$

$$b = -0.3 \quad \text{(summer)}$$

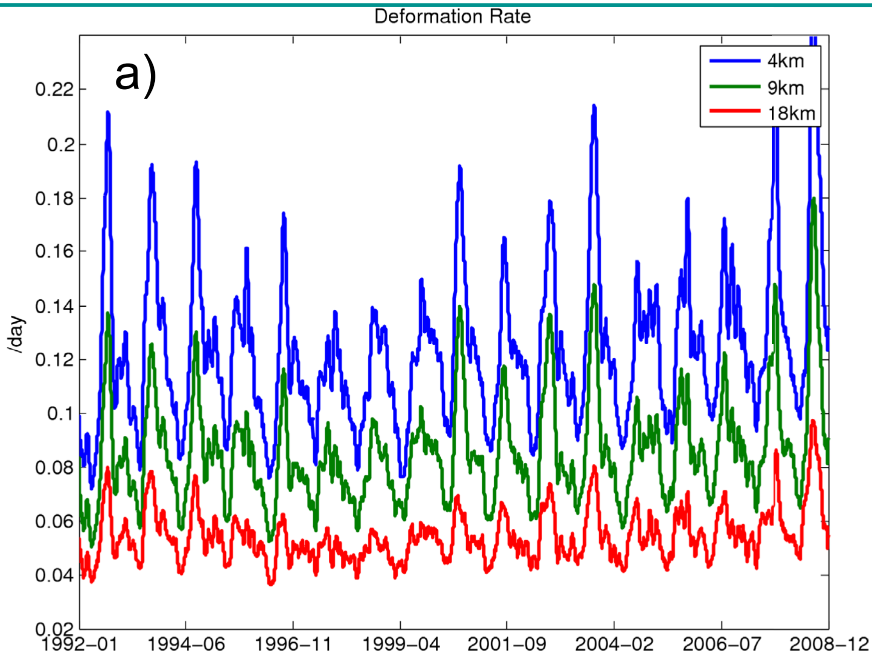
$$d: \ \text{base deformation rate}$$





RGPS

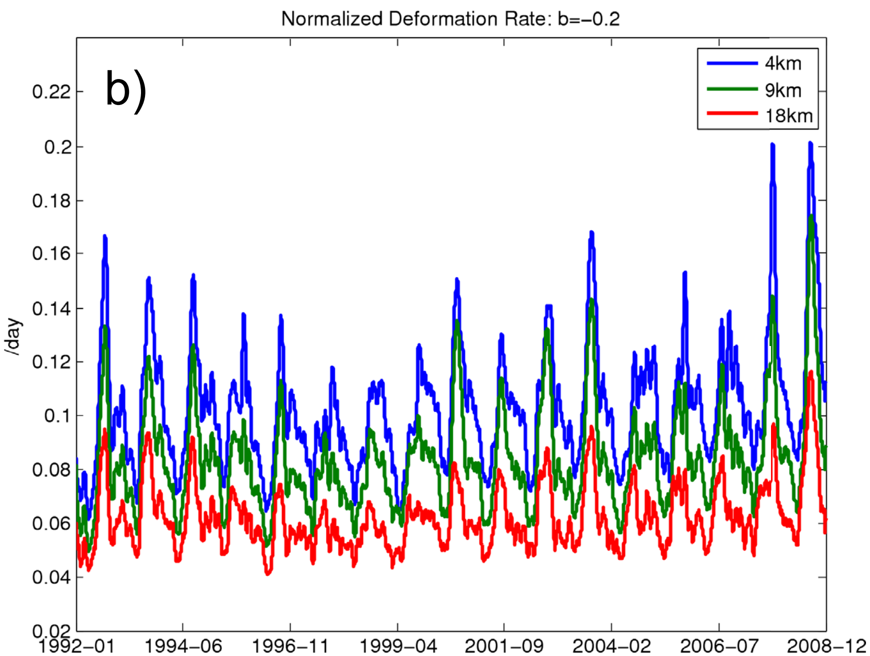
Deformation Rate From Model

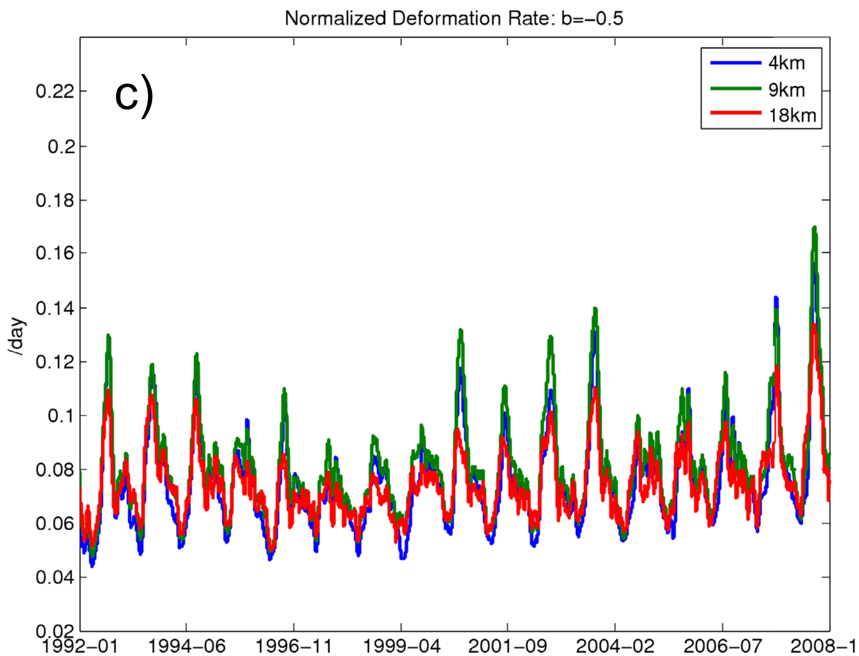


a) Original deformation $D=\sqrt{\mathrm{div}^2+\mathrm{shear}^2}$ for three model resolutions (18, 9 and 4.5 km).

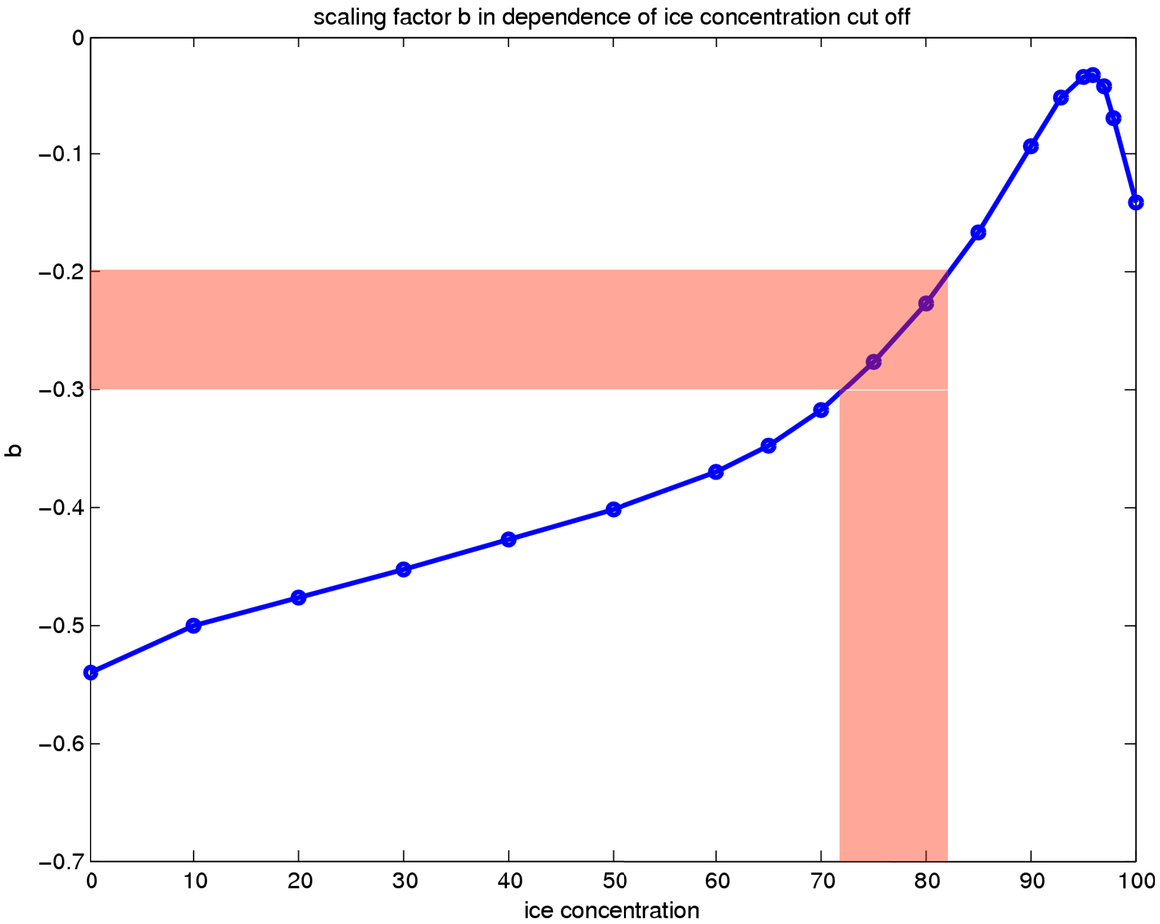
b) Scaled deformation *d* with power law scaling parameters *b* = -0.2 (winter) and -0.3 (summer) for RGPS data (Stern & Lindsay, 2009).

c) Scaled deformation *d* with power law scaling parameters *b* = -0.54 found by least square fit of three model resolutions.





Scale factor vs. ice concentration



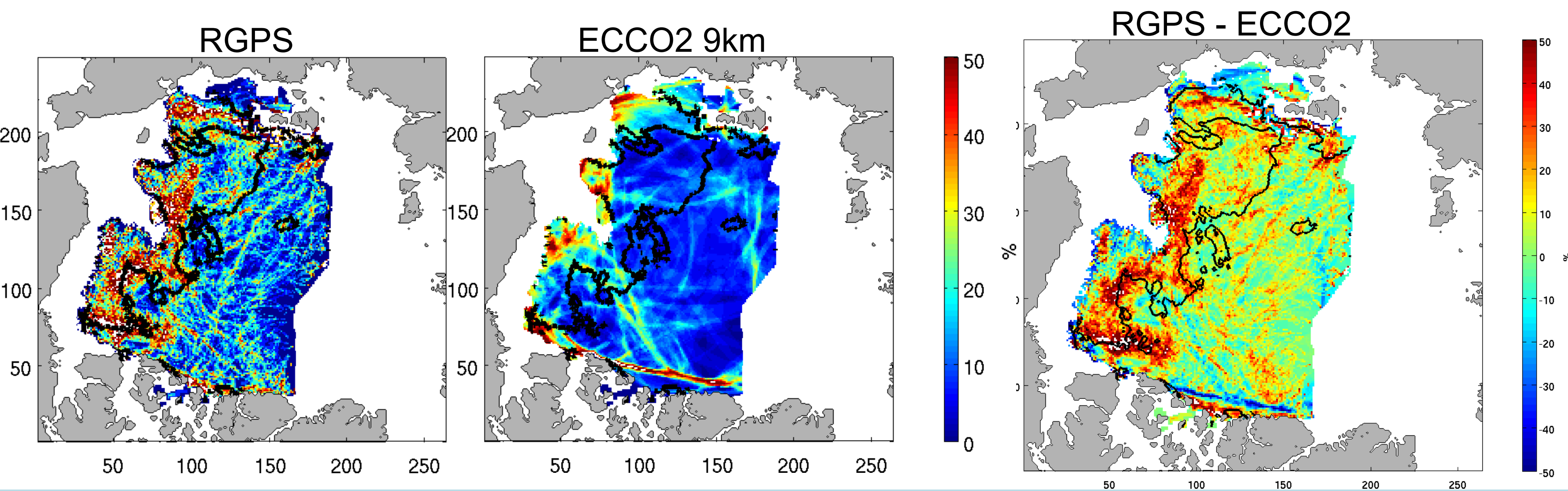
- In the model the power law scaling factor *b* strongly depends on the ice concentration range used.
- For an ice concentration cut off of 80% or for only multi-year ice *b* becomes similar to the observed RGPS scaling factor (-0.2).
- RGPS data is only obtained in high ice concentration regions

- However, also for RGPS the changing fraction of open water could be responsible for most of the observed variability of the scaling factor (in theory *b* should be -0.67 for free drift).
- In the model the power law scale dependence for high ice concentrations is small (*b* > -0.1)

Fractional Number of Deformed Cells

- Due to the complex scaling dependence of the deformation rate the absolute deformation can not compared directly for different resolutions
- Using the fractional number of times a grid cell was deformed (div > 0.02/day OR shear > 0.03/day) during a given period for comparisons.

Nov./Dec. 1998



Sea ice pressure formulation: $P_{max} = P^* h^n e^{[C^*(1-a)]}$

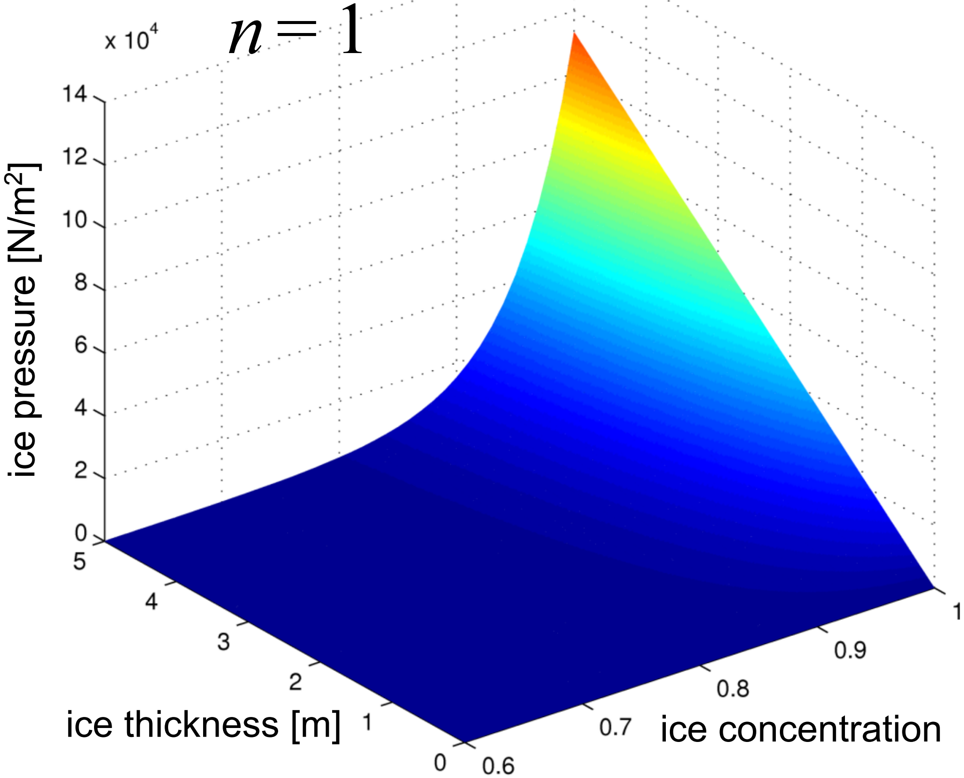
h : ice thickness, $C^* = -20$

a : ice concentration

Control parameterization:

$P^* = 22640$

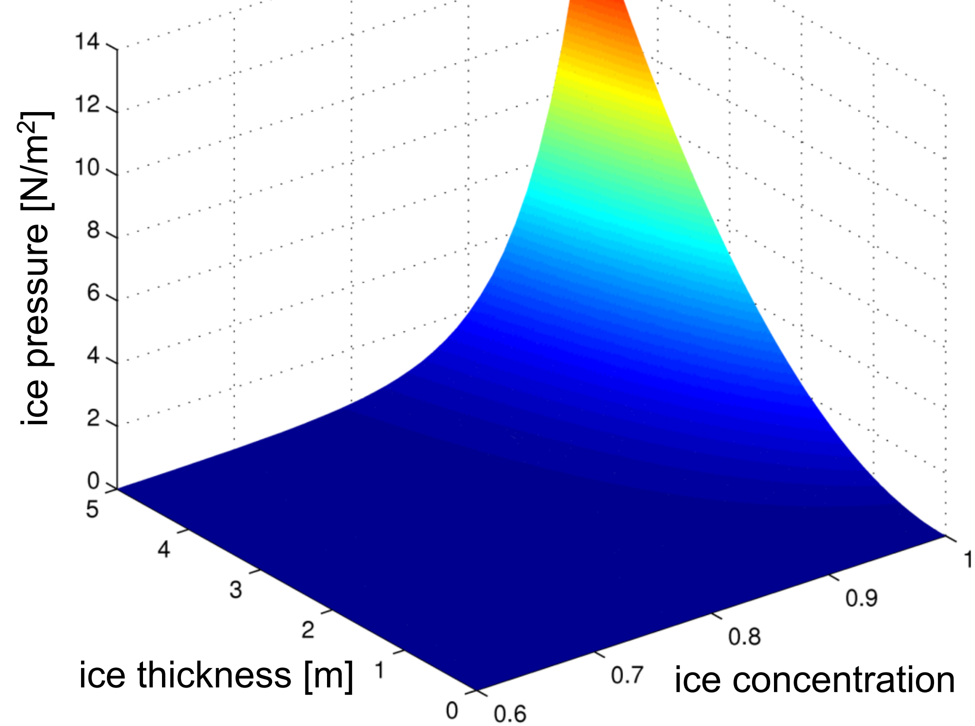
$n = 1$



Test parameterization:

$P^* = 5660$

$n = 2$



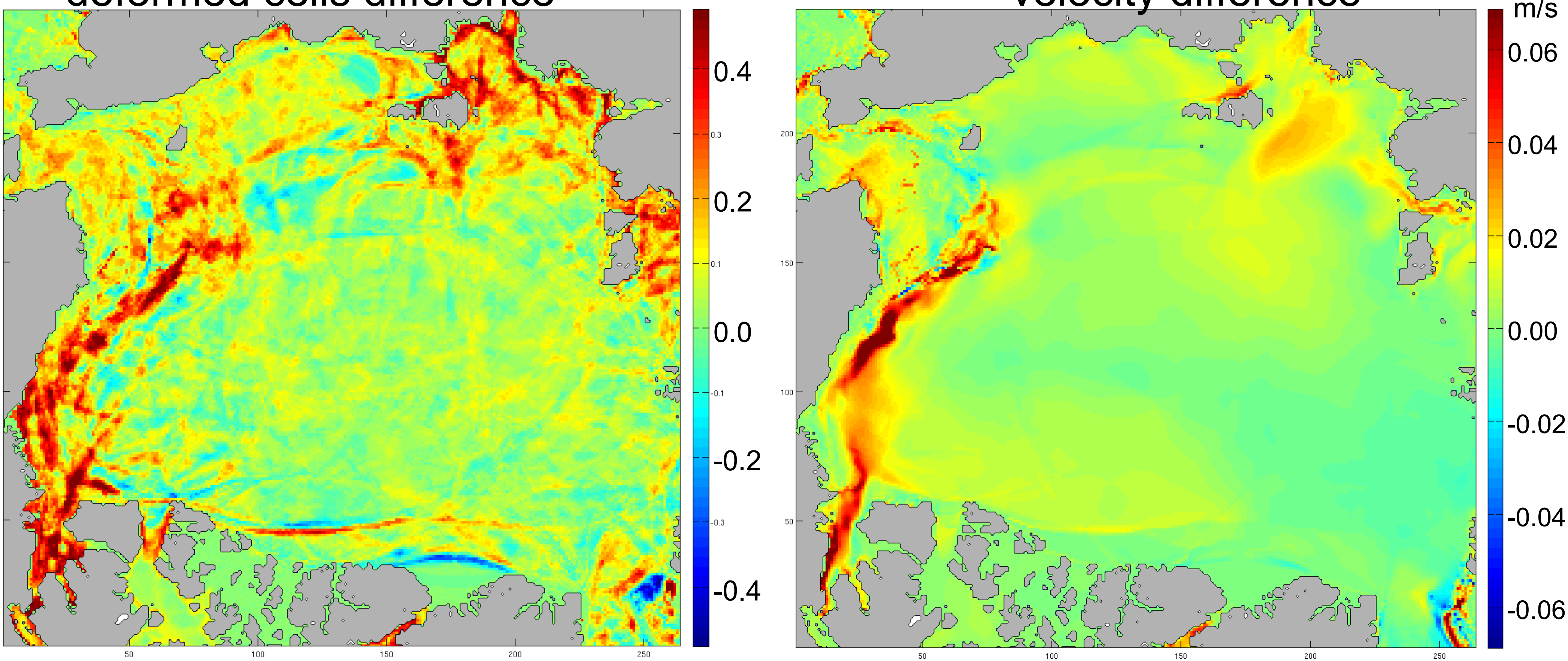
Test – Control Difference

- Difference in fract. number of deformed cells and velocity: Test – Control ice strength formulation

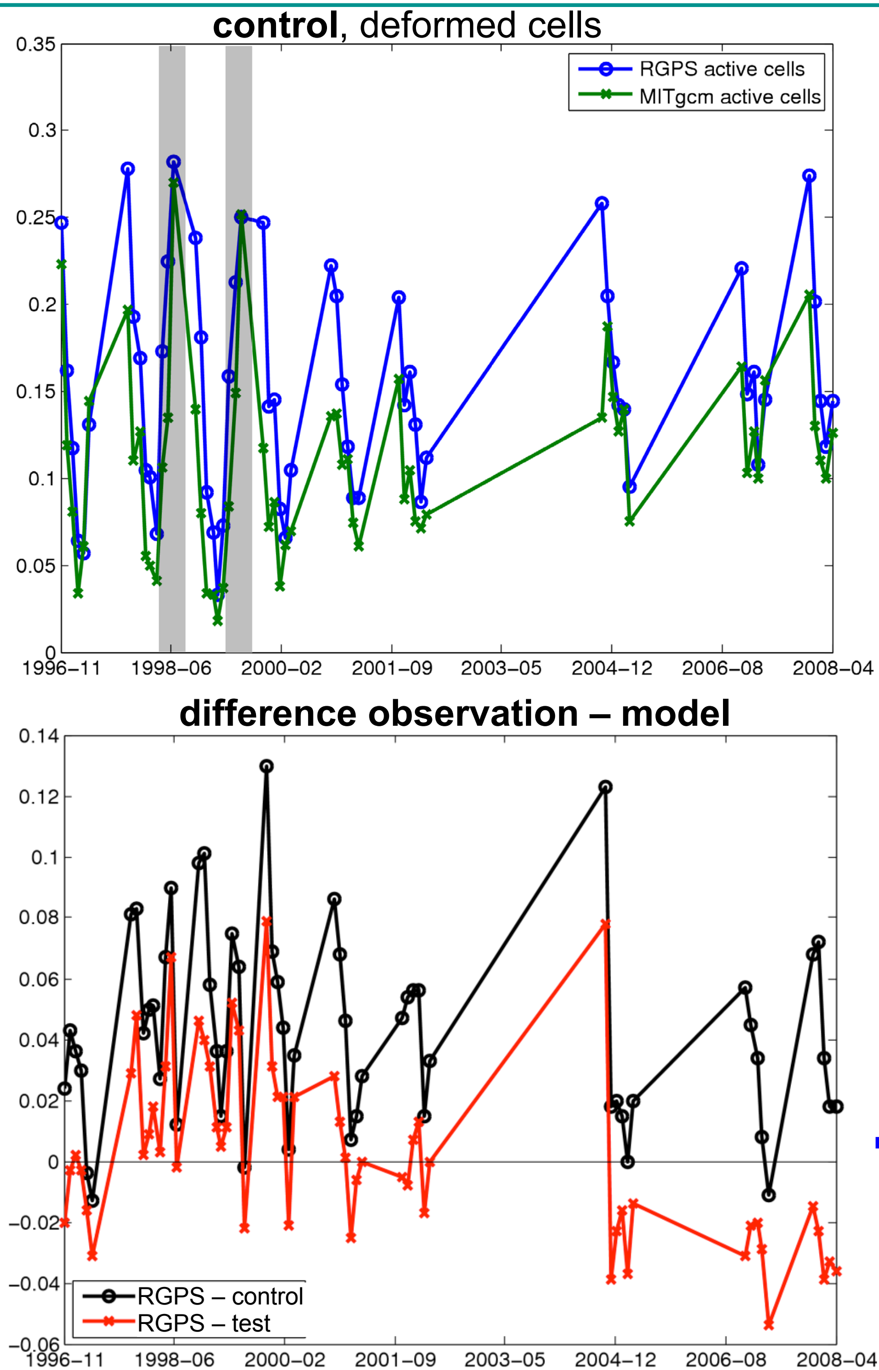
➔ More deformed cells, especially in seasonal ice zone.

➔ higher ice velocity in seasonal ice zone.

deformed cells difference Nov./Dec. 1997 velocity difference



Time Series of Deformed Cells



Time series of deformed cells 1996-2008 (only two summers).

Difference RGPS–ECCO2					
	mean [%]			st. dev.	corr.
	all	MY	FY	all	all
18km control	4.3	3.0	7.0	8.4	0.86
18km test	0.3	0.6	1.3	5.7	0.88
9km control	4.2	2.5	7.5	8.3	0.86
9km test	-0.1	-0.4	1.0	5.9	0.90

All: 58 months

MY, FY: 26 months

➔ New ice pressure formulation improves ice deformation distribution independent of model resolution.

Conclusions

- Sea ice deformation fields from observed RGPS data and ECCO2 model results are different, especially for small scale deformations and linear kinematic features (LKF).

➔ model physics seem to be inadequate for correct reproduction of some aspects of sea ice kinematics.

- Increase in model resolution produces more and stronger confined ice deformation features.
- The observed power law scaling of sea ice deformation can also be found in the model. However, the scaling exponent almost exclusively depends on the considered sea ice concentration range.
- By changing the model sea ice strength formulation away from the linear dependence on ice thickness the modeled and observed deformation fields are getting more consistent.

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Thank you!

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